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(54) RF/VHF IMPEDANCE MATCHING, 4 QUADRANT, DUAL DIRECTIONAL COUPLER WITH V_{RMS}/I_{RMS} RESPONDING DETECTOR CIRCUITRY

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H01J 37/32 (2006.01)
H03H 7/40 (2006.01)

(52) **U.S. Cl.**
CPC ***H01J 37/32183*** (2013.01); ***H03H 7/40*** (2013.01)

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USPC 315/111.11–111.19; 156/345.28, 156/345.44–345.49; 204/192.1–192.18
See application file for complete search history.

(56) **References Cited**

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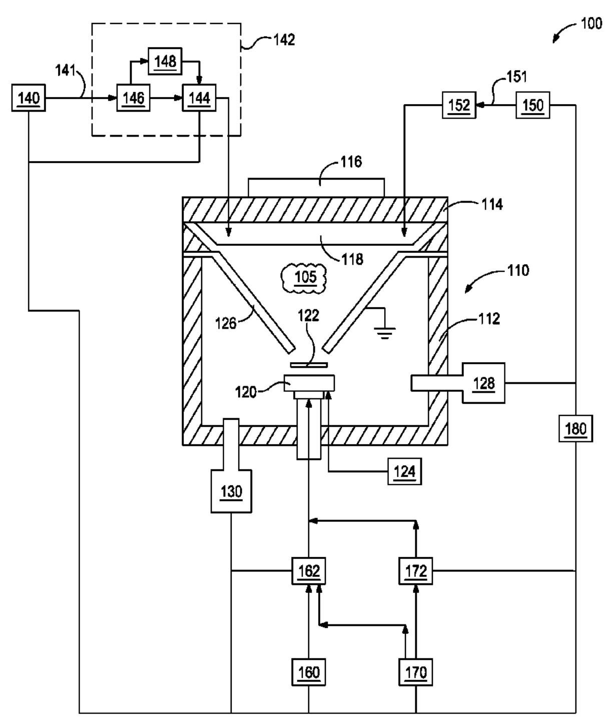
(57) **ABSTRACT**

A physical vapor deposition system may include an RF generator configured to transmit an AC process signal to a physical vapor deposition chamber via an RF matching network. A detector circuit may be configured to sense the AC process signal and output a DC magnitude error signal and a DC phase error signal. A controller may be coupled to the detector circuit and the RF matching network and configured to receive the DC magnitude and phase error signals and to vary an impedance of the RF matching network in response to the DC magnitude and phase error signals.

20 Claims, 3 Drawing Sheets



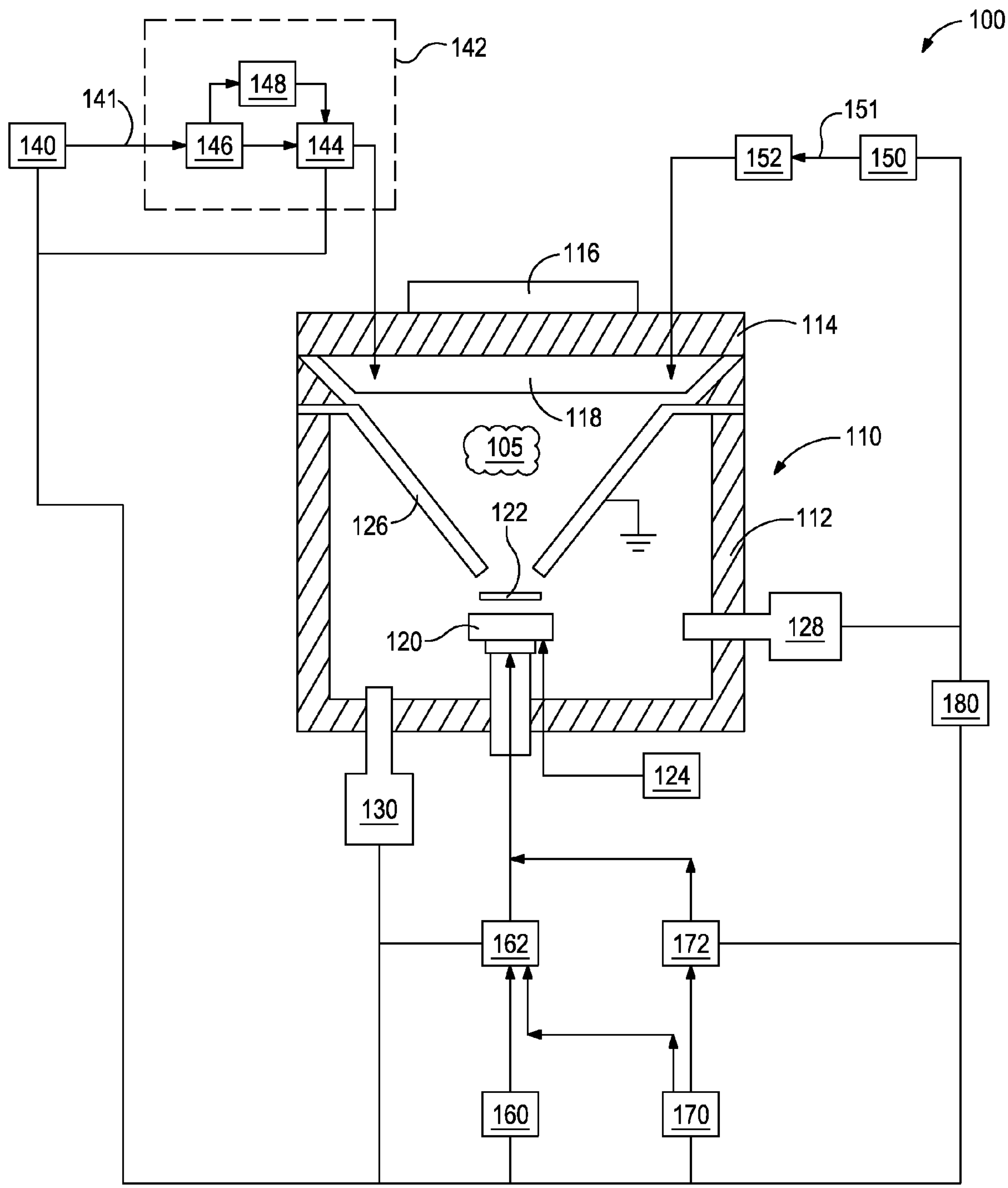

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FIG. 1

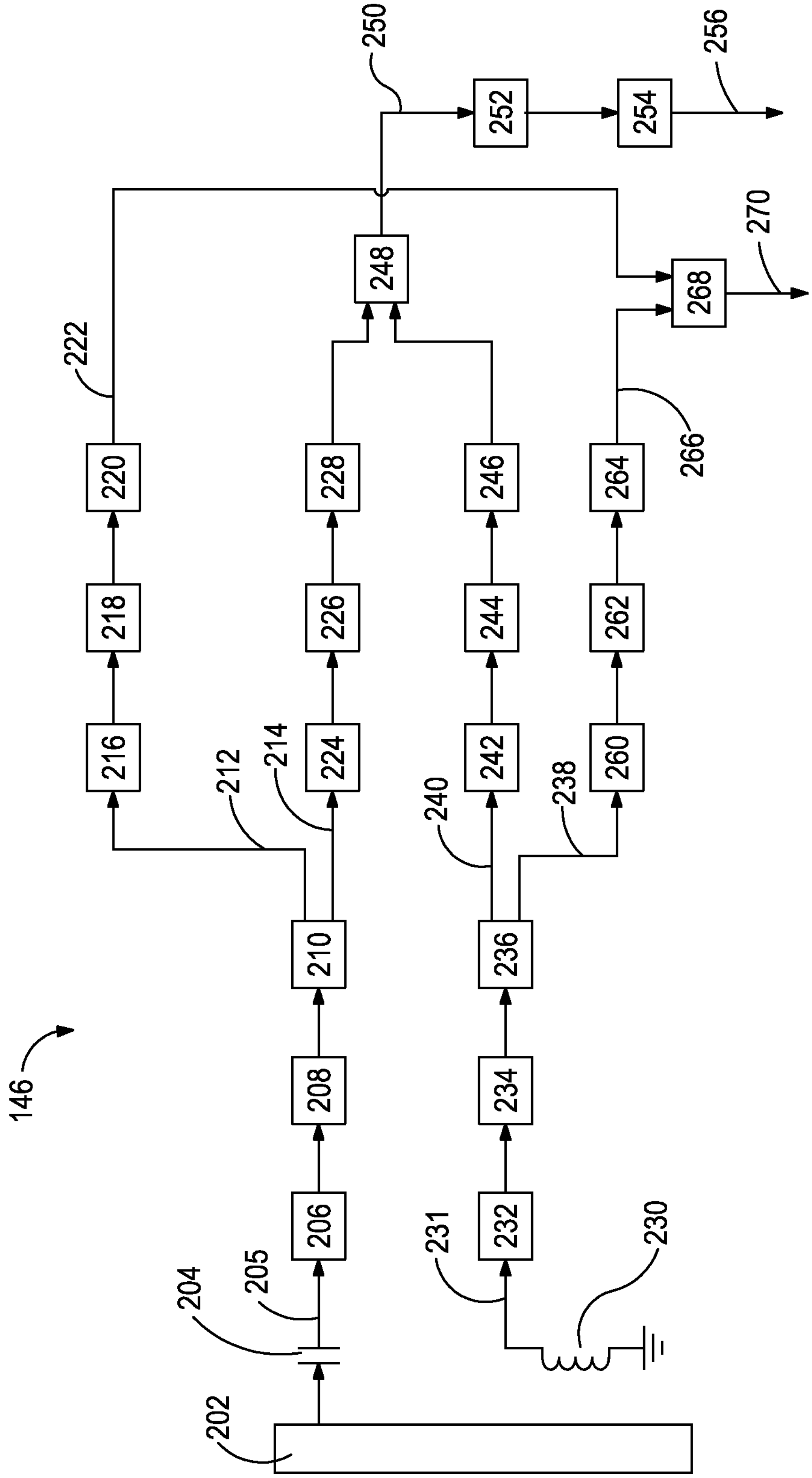
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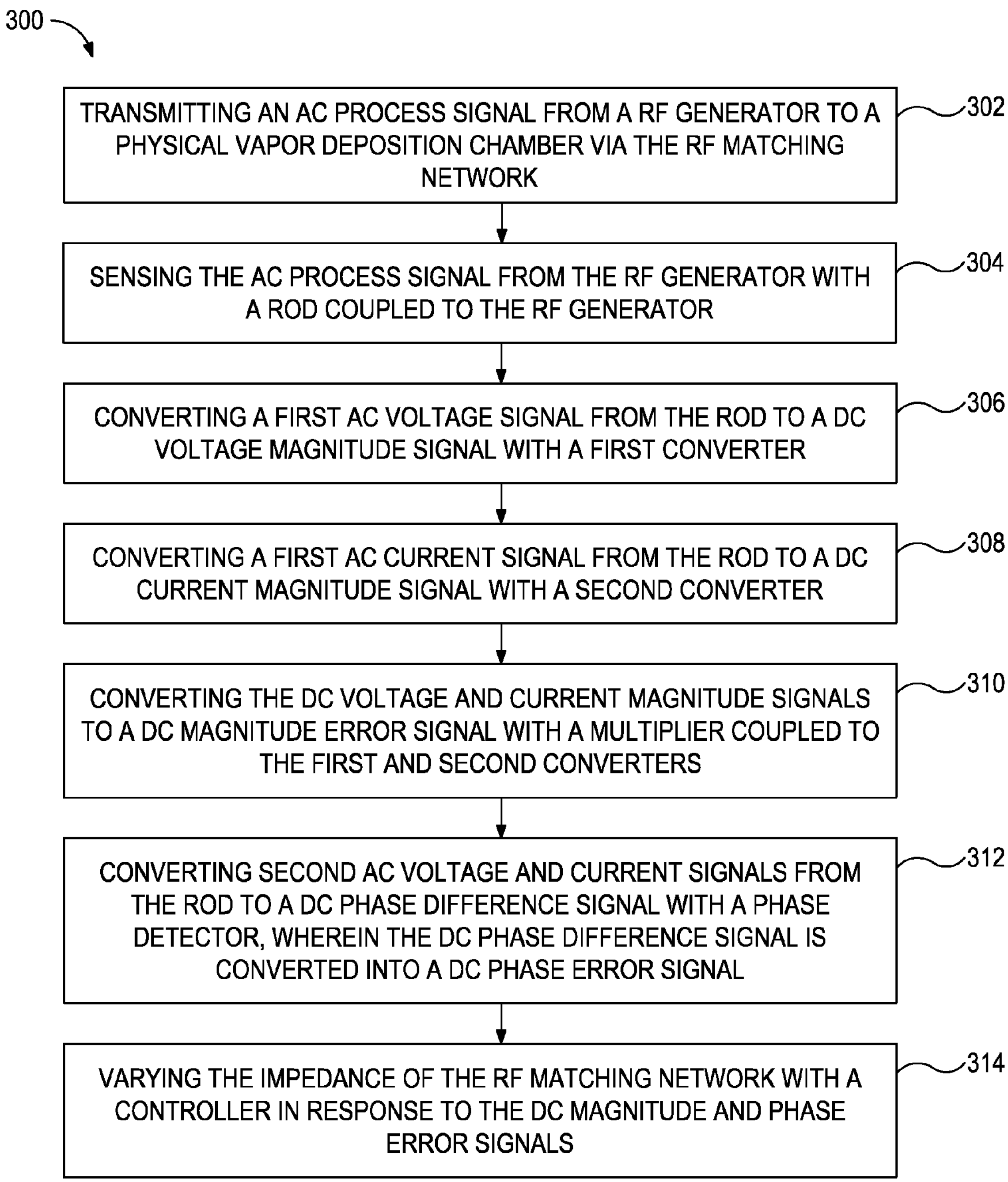
FIG. 2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TRANSMITTING AN AC PROCESS SIGNAL FROM A RF GENERATOR TO A PHYSICAL VAPOR DEPOSITION CHAMBER VIA THE RF MATCHING NETWORK
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SENSING THE AC PROCESS SIGNAL FROM THE RF GENERATOR WITH A ROD COUPLED TO THE RF GENERATOR
304
CONVERTING A FIRST AC VOLTAGE SIGNAL FROM THE ROD TO A DC VOLTAGE MAGNITUDE SIGNAL WITH A FIRST CONVERTER
306
CONVERTING A FIRST AC CURRENT SIGNAL FROM THE ROD TO A DC CURRENT MAGNITUDE SIGNAL WITH A SECOND CONVERTER
308
CONVERTING THE DC VOLTAGE AND CURRENT MAGNITUDE SIGNALS TO A DC MAGNITUDE ERROR SIGNAL WITH A MULTIPLIER COUPLED TO THE FIRST AND SECOND CONVERTERS
310
CONVERTING SECOND AC VOLTAGE AND CURRENT SIGNALS FROM THE ROD TO A DC PHASE DIFFERENCE SIGNAL WITH A PHASE DETECTOR, WHEREIN THE DC PHASE DIFFERENCE SIGNAL IS CONVERTED INTO A DC PHASE ERROR SIGNAL
312
VARYING THE IMPEDANCE OF THE RF MATCHING NETWORK WITH A CONTROLLER IN RESPONSE TO THE DC MAGNITUDE AND PHASE ERROR SIGNALS
314

FIG. 3

RF/VHF IMPEDANCE MATCHING, 4 QUADRANT, DUAL DIRECTIONAL COUPLER WITH V_{RMS}/I_{RMS} RESPONDING DETECTOR CIRCUITRY

CROSS-REFERENCE TO RELATED APPLICATIONS

This non-provisional application claims the benefit under 35 U.S.C. §120 of U.S. application Ser. No. 12/908,755, filed Oct. 20, 2010, entitled "RF/VHF IMPEDANCE MATCHING, 4 QUADRANT, DUAL DIRECTIONAL COUPLER WITH V_{RMS}/I_{RMS} RESPONDING DETECTOR CIRCUITRY," and issued on Aug. 12, 2014, as U.S. Pat. No. 8,803,424. The content of this application is hereby incorporated by reference in its entirety to the extent consistent with the present disclosure.

BACKGROUND

Physical vapor deposition ("PVD") systems are used to deposit thin layers of a target material onto a substrate. PVD systems generally include a radio frequency ("RF") generator that transmits a signal to a deposition chamber. An RF match having a variable impedance is generally located between the RF generator and the chamber. The RF match may be tuned, i.e., the impedance may be varied, to make the impedance of the RF match be the complex conjugate of the deposition chamber's impedance. Tuning the RF match reduces reflected power from the chamber, thereby increasing the power transferred from the RF generator to the chamber and into the plasma deposition process.

Conventional RF matches, however, are slow-acting, resulting in a power loss. Moreover, conventional RF matches often begin tuning in the wrong direction and have difficulty identifying and correcting this error. There is a need, therefore, for an improved RF match that overcomes the deficiencies of conventional systems.

SUMMARY

Embodiments of the disclosure may provide a physical vapor deposition system. The system may include an RF generator configured to transmit an AC process signal to a physical vapor deposition chamber via an RF matching network. A rod may be coupled to the RF generator and configured to sense the AC process signal generated by the RF generator. A first converter may be coupled to the rod and configured to receive a first AC voltage signal from the rod and to output a DC voltage magnitude signal. A second converter may be coupled to the rod and configured to receive a first AC current signal from the rod and to output a DC current magnitude signal. A multiplier may be coupled to the first and second converters and configured to receive the DC voltage and current magnitude signals and to output a DC magnitude error signal. A phase detector may be coupled to the rod and configured to receive a second AC voltage signal and a second AC current signal from the rod and to output a DC phase difference signal, and the DC phase difference signal may be converted into a DC phase error signal. A controller may be coupled to the multiplier, the phase detector, and the RF matching network and configured to receive the DC magnitude and phase error signals and to vary an impedance of the RF matching network in response to the DC magnitude and phase error signals.

Embodiments of the disclosure may also provide a method for varying an impedance of an RF matching network in a physical vapor deposition system. The method may include transmitting an AC process signal from an RF generator to a physical vapor deposition chamber via the RF matching network. The method may also include sensing the AC process signal generated by the RF generator with a rod coupled to the RF generator. The method may further include converting a first AC voltage signal from the rod to a DC voltage magnitude signal with a first converter. The method may further include converting a first AC current signal from the rod to a DC current magnitude signal with a second converter. The method may further include converting the DC voltage and current magnitude signals to a DC magnitude error signal with a multiplier coupled to the first and second converters. The method may further include converting second AC voltage and current signals from the rod to a DC phase difference signal with a phase detector, wherein the DC phase difference signal is converted into a DC phase error signal. The method may further include varying the impedance of the RF matching network with a controller in response to the DC magnitude and phase error signals.

Embodiments of the disclosure may further provide a detector circuit for a physical vapor deposition system. The detector circuit may include a rod configured to sense an AC process signal transmitted from an RF generator to a physical vapor deposition chamber. A first converter may be coupled to the rod and configured to receive a first AC voltage signal from the rod and to output a DC voltage magnitude signal. A second converter may be coupled to the rod and configured to receive a first AC current signal from the rod and to output a DC current magnitude signal. A multiplier may be coupled to an output of the first and second converters and configured to receive the DC voltage and current magnitude signals and to output a DC magnitude error signal. A phase detector may be coupled to the rod and configured to receive a second AC voltage signal and a second AC current signal from the rod and to output a DC phase difference signal, and the DC phase difference signal may be converted into a DC phase error signal. At least one of the first converter, the second converter, the multiplier, and the phase detector may include a telecommunications integrated circuit.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure is best understood from the following detailed description when read with the accompanying Figures. It is emphasized that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

FIG. **1** illustrates an exemplary physical vapor deposition system, according to one or more embodiments described.

FIG. **2** illustrates an exemplary detector circuit from FIG. **1**, according to one or more embodiments described.

FIG. **3** illustrates an exemplary method for varying an impedance of an RF matching network, according to one or more embodiments described.

DETAILED DESCRIPTION

It is to be understood that the following disclosure describes several exemplary embodiments for implementing different features, structures, or functions of the invention. Exemplary embodiments of components, arrangements, and configurations are described below to simplify the present disclosure, however, these exemplary embodiments are provided merely as examples and are not intended to limit the scope of the invention. Additionally, the present disclosure may repeat reference numerals and/or letters in the various exemplary embodiments and across the Figures provided herein. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various exemplary embodiments and/or configurations discussed in the various Figures. Moreover, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second features are formed in direct contact, and may also include embodiments in which additional features may be formed interposing the first and second features, such that the first and second features may not be in direct contact. Finally, the exemplary embodiments presented below may be combined in any combination of ways, i.e., any element from one exemplary embodiment may be used in any other exemplary embodiment, without departing from the scope of the disclosure.

Additionally, certain terms are used throughout the following description and claims to refer to particular components. As one skilled in the art will appreciate, various entities may refer to the same component by different names, and as such, the naming convention for the elements described herein is not intended to limit the scope of the invention, unless otherwise specifically defined herein. Further, the naming convention used herein is not intended to distinguish between components that differ in name but not function. Further, in the following discussion and in the claims, the terms "including" and "comprising" are used in an open-ended fashion, and thus should be interpreted to mean "including, but not limited to." All numerical values in this disclosure may be exact or approximate values unless otherwise specifically stated. Accordingly, various embodiments of the disclosure may deviate from the numbers, values, and ranges disclosed herein without departing from the intended scope. Furthermore, as it is used in the claims or specification, the term "or" is intended to encompass both exclusive and inclusive cases, i.e., "A or B" is intended to be synonymous with "at least one of A and B," unless otherwise expressly specified herein.

FIG. **1** illustrates an exemplary physical vapor deposition ("PVD") system **100** of this disclosure. The PVD system **100** may include a chamber **110** having a body **112** and a lid or ceiling **114**. A magnet assembly **116** may be disposed on an outer side of the lid **114**. In at least one embodiment, the magnet assembly **116** may be a permanent magnet disposed on a plate that is rotated by a motor between about 0.1 and about 10 revolutions per second. For example, the magnet assembly **116** may rotate in a counterclockwise direction at about 1 revolution per second.

A target **118** is generally positioned on an inner side of the lid **114** generally opposite the magnet assembly **116**. In at least one embodiment, the target **118** may be at least partially composed of, but is not limited to, elements such as, borides, carbides, fluorides, oxides, silicides, selenides, sulfides, tellerudes, precious metals, alloys, intermetallics, or the like. For example, the target **118** may be composed of copper (Cu), silicon (Si), gold (Au), titanium (Ti), tantalum (Ta), tungsten (N), aluminum (Al), a combination thereof, or the like.

A pedestal **120** may be disposed in the chamber **110** and configured to support a substrate **122**. In at least one embodiment, the pedestal **120** includes a chuck configured to hold the substrate **122** to the pedestal **120**. Suitable chucks may include mechanical chucks, vacuum chucks, electrostatic chucks ("e-chucks"), or the like. Mechanical chucks include one or more clamps to hold the substrate **122** to the pedestal **120**. Vacuum chucks include a vacuum aperture coupled to a vacuum source to hold the substrate **122** to the pedestal **120**. E-chucks rely on the electrostatic pressure generated by an electrode to hold the substrate **122** to the pedestal **120**. In at least one embodiment, the pedestal **122** may be or include an e-chuck powered by a DC power supply **124**.

A shield **126** may at least partially surround the pedestal **120** and the substrate **122** and be electrically grounded, for example, by physical attachment to the chamber body **112**. The shield **126** is generally configured to receive deposition particles that would normally deposit on the interior walls of the chamber **110** during the PVD process.

A gas supply **128** may be coupled to the chamber **110** and configured to introduce a controlled flow of a process gas into the chamber **110**. In at least one embodiment, the process gas introduced to the chamber **110** may include Argon (Ar), Nitrogen (N_2), Hydrogen (H_2), Helium (He), Xenon (Xe), a combination thereof, or the like.

A vacuum pump **130** may be coupled to the chamber **110** and configured maintain a desired sub-atmospheric pressure or vacuum level in the chamber **110**. In at least one embodiment, the vacuum pump **130** may maintain a pressure of between about 1 and about 100 millitorrs in the chamber **110** during a deposition process.

A first radio frequency ("RF") generator **140** may be configured to supply an AC process signal **141** at a frequency F**1** to the chamber **110**. In at least one embodiment, F**1** may be between about 30 Hz and about 300 MHz. For example, F**1** may be between about 30 MHz and about 162 MHz. A first RF match system **142** may be coupled to the RF generator **140** and configured to decrease reflected power from the load, i.e., the chamber **110**, thereby increasing the power transferred from the RF generator **140** to the chamber **110**. The RF match system **142** may be or include an RF matching network **144** having a variable impedance. The power transfer from the first RF generator **140** to the chamber **110** via the RF matching network **144** is maximized when the impedance of the RF matching network **144** is adjusted to equal or approximate the complex conjugate of the impedance of the chamber **110**. In at least one exemplary embodiment, when the impedance of the RF matching network **144** reaches the complex conjugate of the impedance of the chamber **110**, the RF generator **140** will see an impedance of about **50** ohms at the input of the RF matching network **144**.

In at least one embodiment, a detector circuit **146** may be coupled to or disposed within the RF match system **142**. The detector circuit **146** may be configured to detect or sense the process signal **141** from the RF generator **140** and to generate a magnitude error signal and a phase error signal.

A match controller **148** may be coupled to the RF matching network **144** and the detector circuit **146**. In at least one embodiment, the match controller **148** may be coupled to or be part of the RF match system **142**. In another embodiment, the match controller **148** may be coupled to or be part of an overall system controller **180**. The match controller **148** may be configured to adjust the impedance of the RF matching network **144** in response to the magnitude and phase error signals from the detector circuit **146** to decrease reflected power from the chamber **110**.

A DC generator **150** may supply a DC signal **151** to the chamber **110**. A DC filter **152** may be coupled to the DC generator **150** and configured to block or prevent the process signal **141** and corresponding harmonics from the RF generator **140** from reaching and damaging the DC generator **150**.

A second RF generator **160** may be configured to supply an AC signal at a frequency F**2** to the pedestal **120**. In at least one embodiment, the signal from the second RF generator **160** may be used to bias the chamber **110** and/or the pedestal **120**. A second RF match system **162** may be coupled to and receive the signal from the second RF generator **160**. The second RF match system **162** may be the same as the first RF match **142** system, e.g., a double input match, or it may be different, as desired.

In at least one embodiment, a third RF generator **170** may be configured to supply a signal at a frequency F**3** to the pedestal **120**. In at least one embodiment, the second RF generator **160** and the third RF generator **170** may be coupled to a single RF match system **162**. In another embodiment, the third RF generator **170** may be coupled to a third RF match system **172**. The third RF match system **172** may be the same as the first and/or second RF match systems **142**, **162**, or it may be different, as desired. Although not shown, one or more additional RF generators and corresponding RF matches may be implemented in the PVD system **100**.

A system controller **180** may be coupled to one or more of the gas supply **128**, the vacuum pump **130**, the RF generators **140**, **160**, **170**, and the DC generator **150**. In at least one embodiment, the system controller **180** may also be coupled to one or more of the RF match systems **142**, **162**, **172**. The system controller **180** may be configured to the control the various functions of each component to which it is coupled. For example, the system controller **180** may be configured to control the rate of gas introduced to the chamber **110** via the gas supply **128**. The system controller **180** may be configured to adjust the pressure within the chamber **110** with the vacuum pump **130**. The system controller **180** may be configured to adjust the output signals from the RF generators **140**, **160**, **170**, and/or the DC generator **150**. In at least one embodiment, the system controller **180** may be configured to adjust the impedances of the RF match systems **142**, **162**, **172**.

FIG. **2** illustrates an exemplary detector circuit **146** from FIG. **1**, according to one or more embodiments described. The detector circuit **146** may include a rod **202** or other device coupled to the RF generator **140** (see FIG. **1**) and configured to detect or sense the process signal **141** from the RF generator **140**. A capacitor **204** may be coupled to the rod **202** and configured to pick up an initial AC voltage (V_{RMS}) signal **205** from the RF generator **140** via the rod **202**. A voltage scaler **206** may be coupled to the capacitor **204** and configured to scale the V_{RMS} signal **205** received from the capacitor **204**, such as with one or more resistors. A low pass filter **208** may be coupled to the voltage scaler **206** and configured to pass frequencies of the scaled V_{RMS} signal **205** below a cutoff frequency and to attenuate frequencies above the cutoff frequency.

A power splitter **210** may be coupled to the low pass filter **208** and configured to split the V_{RMS} signal **205** from the low pass filter **208** and output a first V_{RMS} signal **212** and a second V_{RMS} signal **214**. In at least one embodiment, the power splitter **210** may be or include a telecommunications integrated circuit (telecom IC) having wide bandwidth capabilities. For example, the telecom IC may be operable at variable frequencies between about 400 kHz and 3 GHz. In at least one embodiment, rather than creating the second V_{RMS} signal **214** with the power splitter **210**, a second capacitor, voltage scaler, and low pass filter (not shown) may be placed in parallel with the capacitor **204**, scaler **206**, and low pass filter **208** to create the second V_{RMS} signal **214**.

A voltage scaler **216** may be coupled to the power splitter **210** and configured to receive and scale the first V_{RMS} signal **212** from the power splitter **210**. The voltage scaler **216** may be the same as the voltage scaler **206**, or it may be a different component, as desired. A clamp **218** may be coupled to the voltage scaler **216** and configured to clamp any overshoot and/or undershoot of the first V_{RMS} signal **212** from the voltage scaler **216**. A converter **220** may be coupled to the clamp **218** and configured to convert the first V_{RMS} signal **212** from the clamp **218** to a voltage magnitude signal **222** in DC form. In at least one embodiment, the converter **220** may be a high frequency, low voltage, linear responding RMS to DC power converter. In at least one embodiment, the converter **220** may be or include a telecom IC having wide bandwidth capabilities. The telecom IC in the converter **220** may be the same as the telecom IC in the power splitter **210**, or it may be a different component, as desired.

An attenuator **224** may be coupled to the power splitter **210** and configured to reduce the amplitude and/or power of the second V_{RMS} signal **214** from the power splitter **210** without appreciably distorting its waveform. A clamp **226** may be coupled to the attenuator **224** and configured to clamp any overshoot and/or undershoot of the second V_{RMS} signal **214** from the attenuator **224**. A band pass filter **228** may be coupled to the clamp **226** and configured to pass frequencies of the V_{RMS} signal **214** from the clamp **226** within a set range and attenuate frequencies outside the set range.

An inductor **230** may be coupled to the rod **202** and configured to pick up an initial AC current (I_{RMS}) signal **231** from the RF generator **140** via the rod **202**. A current scaler **232** may be coupled to the inductor **230** and configured to scale the I_{RMS} signal **231** received from the inductor **230**. A low pass filter **234** may be coupled to the current scaler **232** and configured to pass frequencies of the scaled I_{RMS} signal **231** from the current scaler **232** below a cutoff frequency and to attenuate frequencies above the cutoff frequency. A power splitter **236** may be coupled to the low pass filter **234** and configured to split the I_{RMS} signal **231** from the low pass filter **234** and output a first I_{RMS} signal **238** and a second I_{RMS} signal **240**. In at least one embodiment, the scaler **232**, low pass filter **234**, and/or power splitter **236** may be the same as the scaler **206**, low pass filter **208**, and/or power splitter **210**, or they may be different, as desired. In at least one embodiment, rather than creating the second I_{RMS} signal **240** with the power splitter **236**, a second inductor, current scaler, and low pass filter (not shown) may be placed in parallel with the inductor **230**, current scaler **232**, and low pass filter **234** to create the second I_{RMS} signal **240**.

An attenuator **242** may be coupled to the power splitter **236** and configured to receive the second I_{RMS} signal **240** from the power splitter **236** and to reduce the amplitude and/or power of the second I_{RMS} signal **240** without appreciably distorting its waveform. A clamp **244** may be coupled to the attenuator **242** and configured to clamp any overshoot and/or undershoot of the second I_{RMS} signal **240** from the attenuator **242**. A band pass filter **246** may be coupled to the clamp **244** and configured to pass frequencies of the second I_{RMS} signal **240** from the clamp **244** within a set range and attenuate frequencies outside the set range. In at least one embodiment, the attenuator **242**, clamp **244**, and/or band pass filter **246** may be the same as the attenuator **224**, clamp **226**, and/or band pass filter **228**, or they may be different components, as desired.

A phase detector **248** may be coupled to the band pass filters **228**, **246** and configured to receive the second V_{RMS} signal **214** from the band pass filter **228** and the second I_{RMS} signal **240** from the band pass filter **246** and to output phase difference signal **250** in DC form that corresponds to the phase difference in degrees or radians between the V_{RMS} signal **214** and the I_{RMS} signal **240**. In at least one embodiment, the phase detector **248** may be an RF/IF gain/phase detector. In at least one embodiment, the phase detector **248** may be or include a telecom IC having wide bandwidth capabilities. The telecom IC in the phase detector **248** may be the same as the telecom IC in the power splitter **210**, the power splitter **236**, and/or the converter **220**, or it may be different, as desired.

A buffer **252** may be coupled to the phase detector **248**, and a scaler **254** may be coupled to the buffer **252** and configured to scale the phase difference signal **250**. The scaler **254** may be the same as one or more of the scalers **206**, **216**, **232**, or it may be different, as desired. The scaler **254** may be configured to output a phase error signal **256** in DC form that corresponds to the phase error between the V_{RMS} signal **214** and the I_{RMS} signal **240**.

A scaler **260** may be coupled to the power splitter **236** and configured to receive and scale the first I_{RMS} signal **238** from the power splitter **236**. A clamp **262** may be coupled to the scaler **260** and configured to clamp any overshoot and/or undershoot of the I_{RMS} signal **238** from the scaler **260**. A converter **264** may be coupled to the clamp **262** and configured to convert the I_{RMS} signal **238** from the clamp **262** to a current magnitude signal **266** in DC form. In at least one embodiment, the converter **264** may be high frequency, low voltage, linear responding $_{RMS}$ to DC power converter. In at least one embodiment, the converter **264** may be or include a telecom IC having wide bandwidth capabilities. The telecom IC in the converter **264** may be the same as the telecom IC in the power splitter **210**, the converter **220**, the power splitter **236**, and/or the phase detector **248**, or it may be a different component, as desired. In at least one embodiment, the scaler **260**, clamp **262**, and/or converter **264** may be the same as the scaler **216**, clamp **218**, and/or converter **220**, or they may be different components, as desired.

A multiplier **268** may be coupled to the converters **220** and **264** and configured to receive the voltage magnitude signal **222** from the converter **220** and the current magnitude signal **266** from the converter **264** and to output a magnitude error signal **270** in DC form. In at least one embodiment, the multiplier **268** may be a 4 quadrant multiplier. In at least one embodiment, the multiplier **268** may be or include a telecom IC having wide bandwidth capabilities. The telecom IC in the multiplier **268** may be the same as the telecom IC in the power splitter **210**, the converter **220**, the power splitter **236**, the phase detector **248**, and/or the converter **264**, or it may be a different component, as desired.

In operation, with continuing reference to FIGS. **1** and **2**, the RF generator **140** is in pulse mode and supplies the pulsing process signal **141** to the target **118** in the chamber **110**. The DC generator **150** also supplies the DC signal **151** to the target **118** in the chamber **110**. The second RF generator **160** and/or the third RF generator **170** supply signal(s) to the pedestal **120** in the chamber **110** providing a bias. Gas is introduced to the chamber **110** from the gas supply **128** to facilitate the formation of plasma **105** within the chamber **110**. Ionized atoms within the plasma **105**, which are positively charged, are attracted to and accelerated toward the target **118**, which is negatively charged. Upon impact with the target **118**, the ionized atoms dislodge atoms from the target **118**. The dislodged atoms become ionized in the plasma **105** and are then accelerated toward the substrate **122** by the magnetic field within the chamber **110**.

The rod **202** senses the signal **141** from the RF generator **140**, and the capacitor **204** picks up the V_{RMS} signal **205** from the rod **202**. The V_{RMS} signal **205** may be scaled and filtered to prevent harmonic distortion from the converter **220**. The V_{RMS} signal **205** may then be power split into a first V_{RMS} signal **212** and a second V_{RMS} signal **214**. The V_{RMS} signal **212** may be scaled, clamped, and driven to the converter **220**. The V_{RMS} signal **212** may then be converted to a voltage magnitude signal **222** in DC form by the converter **220**. The V_{RMS} signal **214** may be attenuated, clamped, filtered, and driven to the phase detector **248**.

The inductor **230** picks up the I_{RMS} signal **231** from the rod **202**. The I_{RMS} signal **231** may be scaled and filtered to prevent harmonic distortion from the converter **264**. The I_{RMS} signal **231** may then be power split into a first I_{RMS} signal **238** and a second I_{RMS} signal **240**. The I_{RMS} signal **240** may be attenuated, clamped, filtered, and driven to the phase detector **248**.

The phase detector **248** may receive the V_{RMS} signal **214** and the I_{RMS} signal **240** and output a signal **250** in DC form that corresponds to the phase difference between the V_{RMS} signal **214** and the I_{RMS} signal **240**. The phase difference signal **250** may be buffered and scaled to produce a phase error signal **256** in DC form that corresponds to the phase error between the V_{RMS} signal **214** and the I_{RMS} signal **240**.

The I_{RMS} signal **238** may be scaled, clamped, and driven to the converter **264**. The I_{RMS} signal **238** may then be converted to a current magnitude signal **266** in DC form by the converter **264**. The voltage magnitude signal **222** and the current magnitude signal **266** may then be converted to a magnitude error signal **270** by the multiplier **268**.

The match controller **148** (see FIG. **1**) may receive the phase error signal **256** and the magnitude error signal **270** from the detector circuit **146**, and based on the signals **256**, **270**, the match controller **148** may adjust the impedance of the RF matching network **144** to reduce and/or eliminate reflected power from the physical vapor deposition chamber **110**. In at least one embodiment, the match controller **148** may also receive the voltage magnitude signal **222** and the current magnitude signal **266**. In at least one embodiment, the match controller **148** may adjust the impedance of the RF matching network **144** by adjusting variable components within the RF matching network **144**. In at least one embodiment, the variable components may be adjusted with stepper motors or the like that are controlled by one or more controllers, such as the match controller **148** or the system controller **180**. In at least one embodiment, the variable components may be or include variable capacitors. As a result, the RF matching network **144** may be auto-tuned to increase power transfer efficiency from the RF generator **140** to the chamber **110**.

FIG. **3** illustrates an exemplary method **300** for varying an impedance of an RF matching network in a physical vapor deposition system, according to one or more embodiments described. The method **300** may include transmitting an AC process signal from an RF generator to a physical vapor deposition chamber via an RF matching network, as shown at **302**. The method **300** may also include sensing the AC process signal generated by the RF generator with a rod coupled to the RF generator, as shown at **304**. The method **300** may further include converting a first AC voltage signal from the rod to a DC voltage magnitude signal with a first converter, as shown at **306**. The method **300** may further include converting a first AC current signal from the rod to a DC current magnitude signal with a second converter, as shown at **308**. The method **300** may further include converting the DC voltage and current magnitude signals to a DC magnitude error signal with a multiplier coupled to the first and second converters, as shown at **310**. The method **300** may further include converting second AC voltage and current signals from the rod to a DC phase difference signal with a phase detector, wherein the DC phase difference signal is converted into a DC phase error signal, as shown at **312**. The method **300** may further include varying the impedance of the RF matching network with a controller in response to the DC magnitude and phase error signals, as shown at **314**.

The foregoing has outlined features of several embodiments so that those skilled in the art may better understand the present disclosure. Those skilled in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions and alterations herein without departing from the spirit and scope of the present disclosure.

I claim:

1. A match system, comprising:

a rod configured to sense an AC process signal;

a first converter coupled to the rod and configured to receive a first AC voltage signal from the rod and to output a DC voltage magnitude signal;

a second converter coupled to the rod and configured to receive a first AC current signal from the rod and to output a DC current magnitude signal;

a multiplier coupled to the first and second converters and configured to receive the DC voltage and current magnitude signals and to output a DC magnitude error signal;

a phase detector coupled to the rod and configured to receive a second AC voltage signal and a second AC current signal from the rod and to output a DC phase difference signal, wherein the DC phase difference signal is converted into a DC phase error signal;

a RF matching network configured to receive the AC process signal; and

a controller coupled to the multiplier, the phase detector, and the RF matching network and configured to receive the DC magnitude and phase error signals and to vary an impedance of the RF matching network in response to the DC magnitude and phase error signals.

2. The match system of claim **1**, further comprising:

a capacitor coupled to the rod and configured to pick up an initial AC voltage signal from the rod, wherein the initial AC voltage signal is converted into at least one of the first and second AC voltage signals; and

an inductor coupled to the rod and configured to pick up an initial AC current signal from the rod, wherein the initial AC current signal is converted into at least one of the first and second AC current signals.

3. The match system of claim **2**, further comprising:

a first power splitter coupled to the capacitor and configured to split the initial AC voltage signal into the first and second AC voltage signals; and

a second power splitter coupled to the inductor and configured to split the initial AC current signal into the first and second AC current signals.

4. The match system of claim **3**, further comprising:

a first scaler coupled in series to the capacitor and configured to receive the initial AC voltage signal from the capacitor;

a first low pass filter coupled in series to the first scaler and the first power splitter and configured to receive the initial AC voltage signal from the first scaler and to transmit the initial AC voltage signal to the first power splitter;

a second scaler coupled in series to the inductor and configured to receive the initial AC current signal from the inductor; and

a second low pass filter coupled in series to the second scaler and the second power splitter and configured to receive the initial AC current signal from the second scaler and to transmit the initial AC current signal to the second power splitter.

5. The match system of claim **3**, further comprising:

a first scaler coupled in series to the first power splitter and configured to receive the first AC voltage signal from the first power splitter;

a first clamp coupled in series to the first scaler and the first converter and configured to receive the first AC voltage signal from the first scaler and to transmit the first AC voltage signal to the first converter;

a second scaler coupled in series to the second power splitter and configured to receive the second AC current signal from the second power splitter; and

a second clamp coupled in series to the second scaler and the second converter and configured to receive the second AC current signal from the second scaler and to transmit the second AC current signal to the second converter.

6. The match system of claim **3**, further comprising:

a first attenuator coupled in series to the first power splitter and configured to receive the second AC voltage signal from the first power splitter;

a first clamp coupled in series to the first attenuator and configured to receive the second AC voltage signal from the first attenuator;

a first band pass filter coupled in series to the first clamp and the phase detector and configured to receive the second AC voltage signal from the first clamp and to transmit the second AC voltage signal to the phase detector;

a second attenuator coupled in series to the second power splitter and configured to receive the second AC current signal from the second power splitter;

a second clamp coupled in series to the second attenuator and configured to receive the second AC current signal from the second attenuator; and

a second band pass filter coupled in series to the second clamp and the phase detector and configured to receive the second AC current signal from the second clamp and to transmit the second AC current signal to the phase detector.

7. The match system of claim **1**, further comprising:

a buffer coupled in series to the phase detector and configured to receive DC phase difference signal; and

a scaler coupled in series to the buffer and configured to receive the DC phase difference signal from the buffer and to output the DC phase error signal.

8. The match system of claim **1**, wherein at least one of the first converter, the second converter, the multiplier, and the phase detector comprises a telecommunications integrated circuit having wide bandwidth capabilities.

9. The match system of claim **8**, wherein the telecommunications integrated circuit is configured to operate between 400 kHz and 3 GHz.

10. The match system of claim **1**, wherein the match system is coupled to a plasma processing chamber and the controller is configured to vary the impedance of the RF matching network to reduce reflected power from the plasma processing chamber.

11. The match system of claim **10**, wherein the RF matching network comprises at least one variable capacitor, and wherein the controller adjusts the at least one variable capacitor to vary the impedance of the RF matching network.

12. A method for varying an impedance of an RF matching network in a match system, comprising:

sensing an AC process signal generated by an RF generator with a rod coupled to the RF generator;

converting a first AC voltage signal from the rod to a DC voltage magnitude signal with a first converter;

converting a first AC current signal from the rod to a DC current magnitude signal with a second converter;

converting the DC voltage and current magnitude signals to a DC magnitude error signal with a multiplier coupled to the first and second converters;

converting second AC voltage and current signals from the rod to a DC phase difference signal with a phase detector, wherein the DC phase difference signal is converted into a DC phase error signal; and

varying the impedance of the RF matching network with a controller in response to the DC magnitude and phase error signals.

13. The method of claim **12**, further comprising scaling and buffering the DC phase difference signal to produce the DC phase error signal.

14. The method of claim **12**, wherein varying the impedance of the RF matching network further comprises adjusting at least one variable capacitor in the RF matching network.

15. The method of claim **14**, further comprising adjusting the at least one variable capacitor with at least one stepper motor.

16. The method of claim **12**, wherein varying the impedance of the RF matching network further comprises varying the impedance of the RF matching network to reduce reflected power from a plasma processing chamber coupled to the match system.

17. The method of claim **12**, wherein at least one of the first converter, the second converter, the multiplier, and the phase detector comprises a telecommunications integrated circuit having wide bandwidth capabilities.

18. A detector circuit, comprising:

a rod configured to sense an AC process signal transmitted from an RF generator to a plasma processing chamber;

a first converter coupled to the rod and configured to receive a first AC voltage signal from the rod and to output a DC voltage magnitude signal;

a second converter coupled to the rod and configured to receive a first AC current signal from the rod and to output a DC current magnitude signal;

a multiplier coupled to an output of the first and second converters and configured to receive the DC voltage and current magnitude signals and to output a DC magnitude error signal; and

a phase detector coupled to the rod and configured to receive a second AC voltage signal and a second AC current signal from the rod and to output a DC phase difference signal, wherein

the DC phase difference signal is converted into a DC phase error signal, and

the DC magnitude error signal and the DC phase error signal are processed such that a power transfer from the RF generator to the plasma processing chamber is maximized.

19. The detector circuit of claim **18**, wherein the DC magnitude error signal and the DC phase error signal are input to an RF match system and are processed such that an impedance of the RF match system is varied to maximize the power transfer.

20. The detector circuit of claim **18**, further comprising:

a capacitor coupled to the rod and configured to pick up an initial AC voltage signal from the rod;

a first power splitter coupled to the capacitor and configured to split the initial AC voltage signal into the first and second AC voltage signals;

an inductor coupled to the rod and configured to pick up an initial AC current signal from the rod; and

a second power splitter coupled to the inductor and configured to split the initial AC current signal into the first and second AC current signals.

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